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Andrew Willson

Forest Conversion and Land Use Change in Rural Northwest Yunnan, China

A Fine-scale Analysis in the Context of the 'Big Picture'



Contrary to the trend of rapid deforestation continuing across Asia, regional assessments point to recent increases in forest cover in China, including Yunnan Province, since the implementation of dramatic forestry policy changes. There is debate about whether the statistics that describe increasing forest cover adequately account for forest status and quality. In this context, the present article aims to quantify forest cover and land use changes in a Tibetan-dominated rural township in northwest Yunnan, China—an ecologically important region affected by recent forest policy changes. Three sequences of Landsat satellite imagery dating from 1981 to late 1999 and other digital datasets were used in a rules-based hybrid classification approach, achieving acceptable accuracy assessment scores.

The results show an average aggregate decline in conifer forests of 23%, mostly due to an active logging industry. Much of this forest has converted to shrubland, which increased in area by over 100%. Grassland also increased, mainly at the expense of cultivation, as a response to increasing dependence on livestock by the rural communities, although high elevation rangelands decreased in area due to changing livelihoods and restrictions by the government on grazing and deliberate burning. Using the accepted definitions of forest and shrubland categories, it was difficult to depict forest and shrubland dynamics due to variation in forest regeneration and afforestation, dieback-affected forests, secondary succession of disused rangelands, and a variety of other mixed community types. Conversion analysis revealed significant forest–shrubland exchanges occurring even during the 1990s when reduction in overall forest cover slowed considerably. The results support the view that the standard categorizations and representations of land cover only portray a partial picture of forest status, as they do not account for multiple conversions that occur between different land covers over time. Due to ongoing forestry programs and increasing utilization of forest resources by local communities, these conversion issues may be significant, with implications for forest quality and biodiversity.

Our understanding of China's forest status will be improved by correlating inventory data with finer-scale spatial datasets to enable conversion analysis in representative ecological regions. This will advance our knowledge of China's forest status and the effectiveness of forest policy for both local rural community needs, as well as for broader ecological conservation.

Keywords: *Classification; forest cover; land use change; land cover change; remote sensing; GIS; Yunnan; China.*

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Introduction

Throughout Asia, the expansion and intensification of agricultural activities are principal reasons for ongoing deforestation (Geist and Lambin 2001; Giri et al 2003). Underlying causes of land use and land cover (LULC) change leading to deforestation and land degradation include rapid economic development, population growth, and poverty (Giri et al 2003). In China, inappropriate institutional and development policies have also been major contributing factors (Wang et al 2004). This is the case for northwest Yunnan, one of the poorest regions of China, where land use has been greatly affected by recent government policies that aim to balance the need to encourage rural development with ecological restoration (Xu and Wilkes 2004; Xu and Ribot 2004). Given the ongoing need to manage natural resources sustainably, access to accurate land use data is important.

The Food and Agriculture Organization of the United Nations (FAO) provides the most definitive and widely used regional and global forest cover and land use statistics. FAO assessments are based on statistics provided by countries, and in the case of China the data are derived from the National Forest Resource Inventory (NFRI). This monitoring reports substantial increases in forest cover in China (including Yunnan) since 1990. However, there is debate about the applicability of the classification systems used, particularly with regard to what constitutes forest cover versus other LULC types, and whether natural forest cover is actually in decline (Sayer and Sun 2003; Rozelle et al 2003).

There are numerous reports of increasing forest cover in China and Yunnan in particular. In 2000, an assessment by the FAO that used NFRI data (FAO 2001) reported that forest cover in China was 17.5%, representing an increase of 12.4% since 1990. However, this figure includes plantations, which accounted for 27.5% of the forest area in 2000. More specifically in Yunnan, the State Forestry Bureau reports that forest cover increased from 25% to 34% from 1978 to 1997, attributable to natural regeneration, replanting, and commercial plantations (Xu and Ribot 2004). The Yunnan Statistical Bureau also describes a similar increase in forest cover to the year 2000, with a corresponding decrease in the "undeveloped land on slope" category, suggesting the success of afforestation activities (YSB 2001). These data are derived from the NFRI.

Consequently, this study first examines LULC changes occurring in a regionally important area in northwest Yunnan, using remote sensing classification techniques with the accepted LULC categories. This area typifies the landform and vegetation types in the

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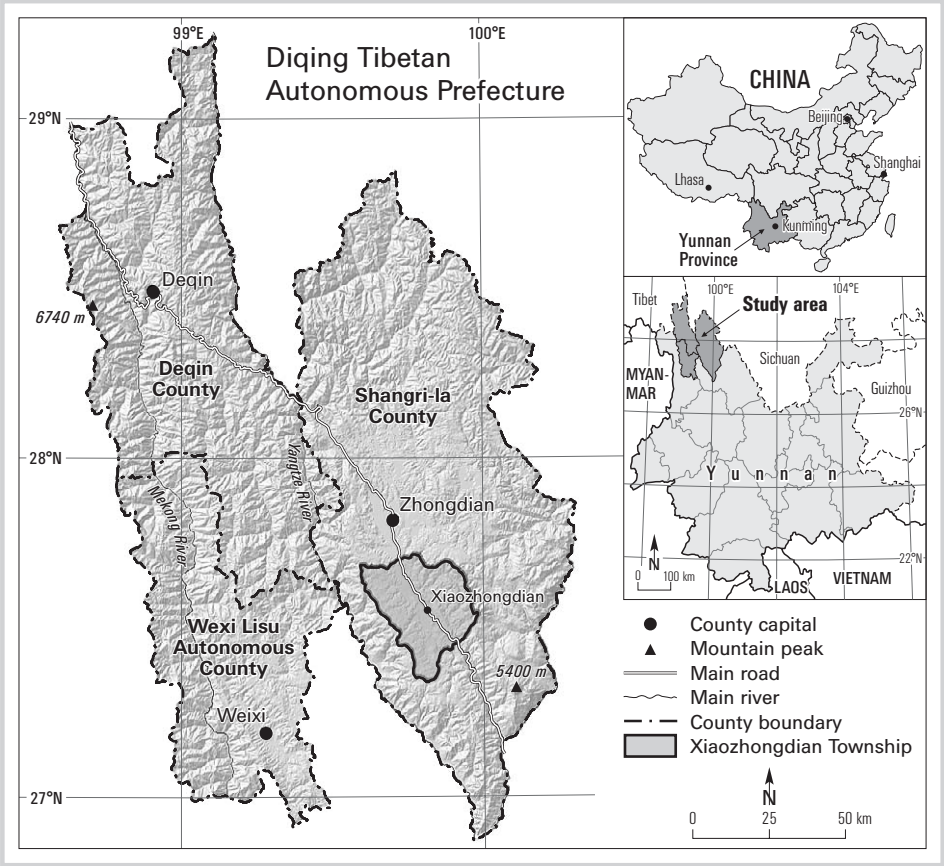


FIGURE 1 Location of Xiaozhongdian Township. (Map by author)

mountainous headwater regions at which major forestry policies have been targeted, hence it is indicative of the effectiveness of these policies on the broader scale. Secondly, the results are evaluated in the context of the bigger picture trends derived from the national data.

Study area

Northwest Yunnan

Northwest Yunnan is situated in the transitional zone between the Qinghai–Tibet and the Yunnan–Guizhou plateaus in the southern area of the East Himalayas. It is the meeting place of the Lancang, Salween and Yangtze rivers. The area is designated as a global biodiversity 'hotspot' (CEPF 2002), and lies within the Three Parallel Rivers of Yunnan Protected Areas world heritage site (UNEP 2004). The Diqing Tibetan Autonomous Prefecture in northwest Yunnan is nearly 24,000 km^2 and is made up of 3 counties (Figure 1). Due to topographic extremities, the climate is variable with predominantly dry winter seasons and rainy summers. In Diqing, 84% of the population consists of ethnic minority groups, Tibetans being the largest at 33% of the total population. Northwest Yunnan is becoming a major focal point for state-led nature and ethnic tourism (Hillman 2003).

Xiaozhongdian Township

Xiaozhongdian Township (27°18′–27°44′ N, 99°33′–99°59′ E) is located in the southern part of Shangri-la County (Figure 1), covering approximately 880 km^2 with an elevation range of 2890–4600 m (average 3630 m). The township is characteristic of northwest Yunnan's landscape—clusters of Tibetan villages surrounded by an intensive mix of land uses with surrounding forests (Figure 2). The summer agricultural growing season extends from April to September–October. The Xiaozhongdian River runs through the township from north to south (and eventually into the Yangtze River), forming a large flatter valley where most of the township's cultivation (barley, buckwheat, potatoes, and turnips) and intensive animal husbandry (yak, yak-cattle hybrids, sheep, goats, pigs, donkeys, and poultry) occurs. Surrounding areas are mountainous, covered by pine forests at lower elevation areas, with mixed coniferous and oak forests and alpine rangelands (often used as summer grazing lands) at higher elevations. These forests are utilized by rural communities as grazing areas and for the collection of various non-timber forest products.

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FIGURE 2 Typical land use mosaic of shrubland, cultivation, grasslands and forested hills surrounding a northwest Yunnan Tibetan village. (Photo by author)



Policy history affecting land use

Land use in northwest Yunnan, as in all of China, was greatly influenced by the introduction of the Household Responsibility System in 1979. This devolved land and management responsibility back to individual households. In the study area the main effect of this was an increase in livestock at the expense of cropping (Xu and Ribot 2004). In 1998 the Chinese Government initiated the Natural Forest Protection Program (NFPP), which included a ban on logging over 30 million ha of forest in the upper reaches of the Yangtze and Yellow rivers. The program also involves large-scale afforestation and reforestation of degraded forests, with the aim of protecting important watersheds, building future timber resources, and enhancing biodiversity (Wang et al 2004). In Diqing Prefecture prior to the ban, the logging industry had been particularly active since the late 1960s; by the mid-1990s, the industry was a major employer of people from rural communities and generated more than 80% of the prefecture's gross income (Hillman 2003). The scale and intensity of logging deleteriously affected biodiversity and forest quality in this region (Xu and Wilkes 2004; Yang et al 2004). Despite the widespread forestry activities, however, there are few reliable spatial data available on forest and land use dynamics during this period.

Materials and methods

Classification system

The classification system used in this study was adapted from the FAO system (FAO 2001) and the Chinese national system adopted in 2002 by the Chinese Land Resources Ministry (Table 1).

Image pre-processing and classification

Three time series of satellite imagery were used: 7 December 1999 (Landsat ETM 132/41, pixel size 30 m); 20 November 1990 (Landsat TM 132/41, pixel size 30 m); 19 October 1981 (Landsat MSS 142/41, pixel size 57 m). Attempts were made to both acquire images at near anniversary dates to ensure similar phenological conditions, and to acquire a more recent image. However, in Yunnan's alpine regions scene selection is very difficult due to seasonal snow and cloud cover. These difficulties were compounded by the problems experienced by the Landsat satellite since June 2003 (USGS 2003).

Each image was geometrically corrected to a common base using a nearest-neighbor algorithm obtaining a mean square error of less than 1 pixel. A 3×3 low pass smoothing filter was applied to all images prior to

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TABLE 1 Land use/land cover classes.

Class label	Criteria	Main local species	Local description
Cultivation	Any cultivated land used for agriculture.	Barley, buckwheat, potato, turnip, rapeseed	Close to and surrounding villages. Bare (post-harvest) at the time of image dates.
Mixed grassland	Dominated by annual or perennial grasses, may include patchy areas of forbs or scattered shrubs (<10%).	Various grasses and forbs	Livestock grazing areas usually surrounding villages and cultivated areas. Includes improved pastures for grazing or fodder.
Shrubland	Shrubs are dominant, ie woody perennial plants, generally 0.5–5 m in height on maturity, without a definite crown (FAO).	*Quercus* spp., *Rhododendron* spp., *Pinus* spp.	Usually a dense woody low layer. May include young plantations. May have deciduous overstorey species (birch, bamboo, etc).
Rangeland	Grassland-dominated, high elevation.	Various alpine grasses and forbs	High-elevation (>3600 m) summer grazing lands.
Forest–fir	Canopy cover >10%, trees >5 m (or potentially higher), >0.5 ha in area (FAO).	*Abies* spp., *Picea* spp., *Quercus* spp.	High elevation, usually tall dense forests. May include patches of deciduous species (bamboo, willow, maple).
Forest–pine	Canopy cover >10%, trees >5 m (or potentially higher), >0.5 ha in area (FAO).	*Pinus yunnanensis, P. aramandii*, *P. desnata*	Lower elevation, mixed understorey. Usually grazed around villages. May include patches of deciduous species.

classification. This technique has been found to improve classification results by reducing spectral variability within classes and enhancing between-class separability (Tottrup 2004). To assist in eliminating false change, improve image contrast and remove unclassifiable areas, a mask was created consisting of topographic shadow, cloud, snow, water, burnt, and other unclassifiable areas. This mask file (15% of the study area) was applied to all images to equalize the total classifiable area between image dates. Thus, the LULC results must be interpreted comparatively, not as true proportions relative to the township area. Consequently, results are presented as percentages of the township area excluding the mask.

The classification method used a combination of unsupervised and supervised techniques. This hybrid method produces better results than using only a single approach (Miller and Yool 2002; Tommervik et al 2003). Classification training areas were chosen on the basis of field-acquired local knowledge at selected sites. At each training area site, information was collected, including a full description of LULC type, GPS coordinate, photograph and forestry history of surrounding forests. In addition, a high-resolution 100-km^2 QuickBird satellite image (located in the southern part of the township) was used for the establishment of training areas. Using the signature sets derived from the training areas, different combinations of bands were evaluated to give the best spectral separability for each desired LULC class.

An unsupervised classification produced 12 clusters (or unidentified classes). Using the training areas, these clusters were merged to create a smaller number of preliminary LULC classes. These preliminary classes were then incorporated with other data; the original image data (band thresholds derived from the training area analysis), Normalized Difference Vegetation Index image, and a Digital Elevation Model to classify the final desired LULC classes. This process was applied to all images using the Knowledge Engineer (KE) tool in ERDAS Imagine software. The KE software provides a rules-based approach to classification, consisting of a user-constructed hierarchy of rules (or decision tree) for each class that facilitates the combining of many different raster and GIS datasets (ERDAS 2002). This integrated approach has been shown to improve classification results (Giannetti et al 2001; Mulders 2001). The final classified images were smoothed by applying a majority 3×3 filter.

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Field data and accuracy assessment

A total of 4 field trips were made before and during the classification process, from early 2003 to mid-2004. Interviews with farmers and government officials were conducted and quantitative LULC assessment data were collected. Two standard criteria were used to assess the accuracy of the classifications: user accuracy and the Kappa coefficient (Congalton 1991). The statistical assessments were conducted using ERDAS's Accuracy Assessment tool.

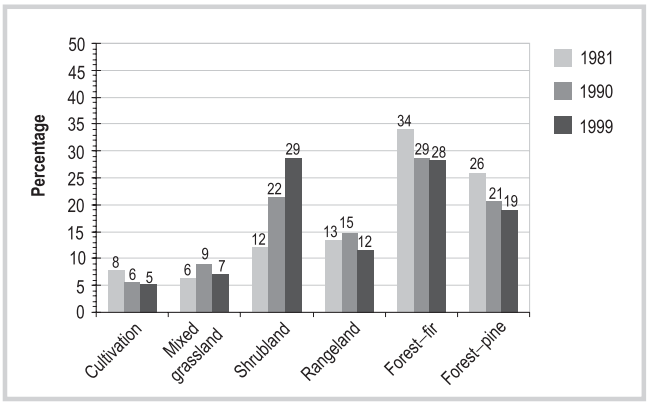
The assessment of the 1999 classification was conducted using field data collected entirely independently of the training data. The aim was to collect at least 300 assessment points for the 6 classes, using a recommended general rule of 50 points per class (Congalton 1991). A first draft of the classification was used to design a stratified sampling design, though this was later refined according to the degree of classification difficulty for each class (based on the spectral separability tests). A total of 194 accuracy assessment points were collected in the field using a GPS connected to a hand-held computer. Where possible, points were recorded at least 30 m (1 pixel) from the LULC boundary. A further 109 random points were created by using the QuickBird satellite image. The points were combined with the field-collected points and overlaid with the classification file for 'desktop' assessment. A total of 303 points were used for assessing the 1999 classification.

Independent reference data could not be used to assess the 1981 and 1990 classifications: historical ancillary data such as vegetation surveys, aerial photography, or other map products were not available. As an alternative, a desktop assessment was undertaken. A total of 256 random assessment points were created, stratified by class, for each classification date. These points were overlaid with the original image and subjectively assigned a class value according to expert knowledge. These class assignments were then compared with the actual classification to produce the assessment statistics. Draft 1981 and 1990 classifications were also qualitatively assessed. Hard copy maps were taken to the field and used in interviews with local forestry employees and village elders regarding logging histories and past land uses, particularly for areas where there was classification uncertainty.

Regional LULC statistics

Both national and Yunnan LULC statistics were obtained from various Chinese published sources and the FAO (particularly the Forest Resource Assessment series of publications). However, the original source of all these statistics is China's NFRI project. These data were compiled from ground surveys of over 200,000 gridded plots distributed across China, updated every 5 years. The inventory is the primary source of all China's forestry data (Piao et al 2005).

FIGURE 3 LULC proportions for 1981, 1990, and 1999. % = amount of each LULC class as a proportion of the total LULC area for that year, excluding the mask.



Results

LULC trends

Classification of the 1981 image shows that forests dominate the LULC classes for Xiaozhongdian Township (forest–fir 34% and forest–pine 26% of township area). In 1990, the dominant LULC class was forest–fir at 29%, followed by shrubland and forest–pine (21% and 22% respectively). In 1999 the dominant LULC classes were shrubland and forest–fir at 29% and 28% respectively, followed by forest–pine at 19% (Figure 3).

There was a decline in cultivation throughout the study period (aggregate decline 37%) but this loss was particularly acute from 1981 to 1990 (Figure 4). Similarly, the greatest decline for both forest classes occurred over this same period. To 1999, the respective aggregate decreases of forest–fir and forest–pine were 17% and 28%. The average aggregate loss of combined

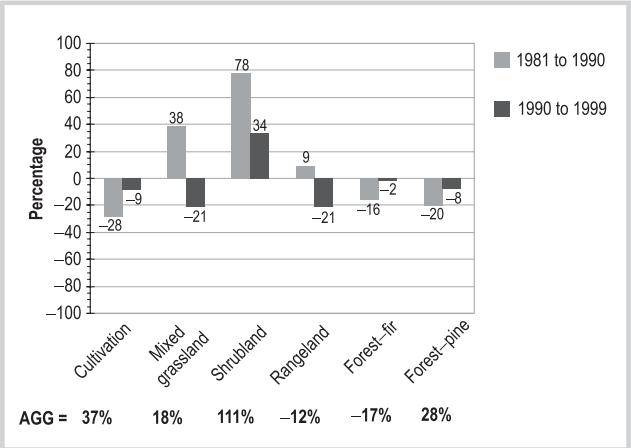
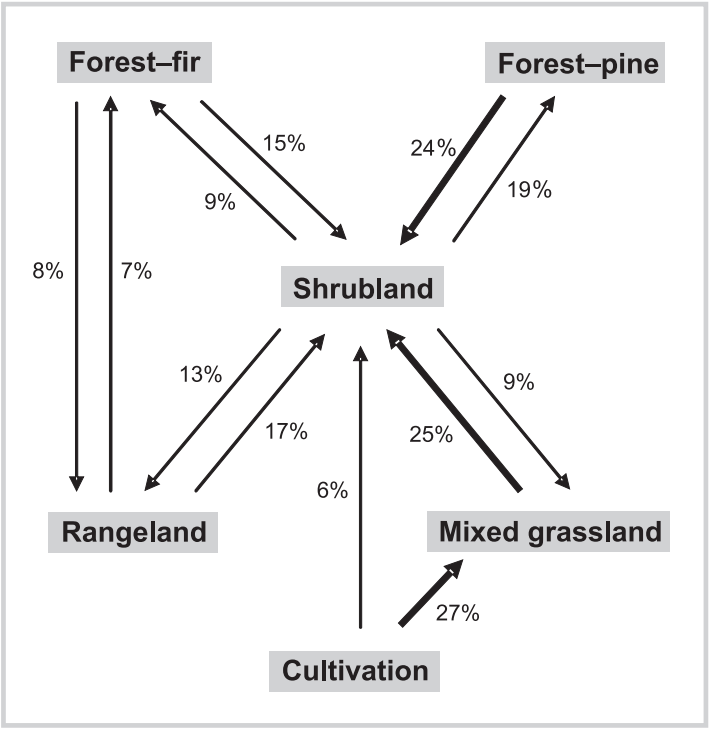


FIGURE 4 LULC rate of change within each class. % calculated by dividing the difference by the base year for each class; figures are rounded; AGG represents the "aggregate change" from 1981 to 1999.

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FIGURE 5 Diagrammatic summary of 1981 to 1990 LULC conversions. % = proportion of the 1981 total for each class; conversions under 5% not shown; bolded arrows highlight more than 20% conversion.



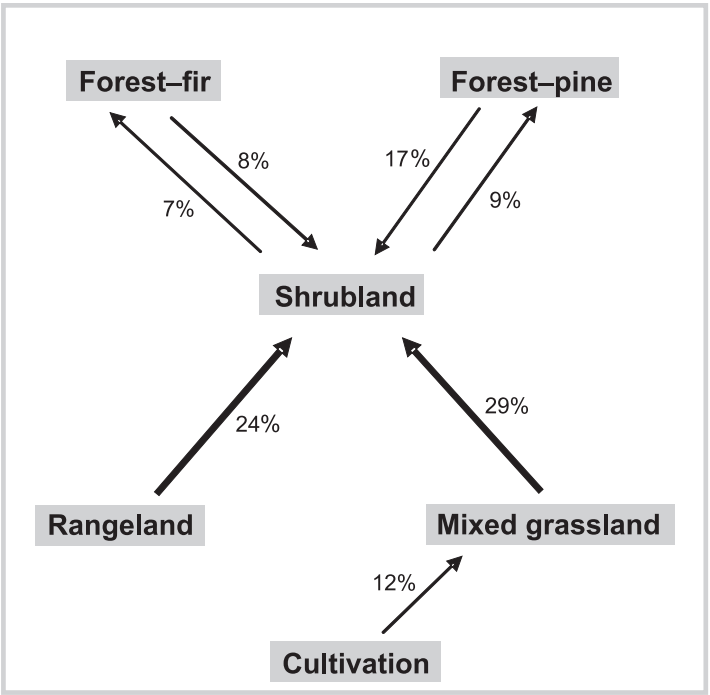


FIGURE 6 Diagrammatic summary of 1990 to 1999 LULC conversions. % = proportion of the 1990 total for each class; conversions under 5% not shown; bolded arrows highlight more than 20% conversion.

forest classes was thus 23%. Shrubland rose steadily by 78% from 1981 to 1990, and further increased by 34% from 1990 to 1999—an aggregate increase of 111%. There was an initial increase of mixed grassland (38%) and rangeland (9%) from 1981 to 1990; however by 1999, both these classes had declined 21% from their 1990 levels. The 1981 to 1999 aggregate change in mixed grassland showed an increase of 18%, while rangeland decreased 12% (Figures 3 and 4).

LULC conversions

Figures 5 and 6 summarize the LULC conversions between the image dates. It is evident that the largest conversions involve the shrubland community, particularly in relation to the forest, rangeland and mixed grassland classes. Mixed grassland was the most important contributor to the increasing shrubland class throughout the study period, followed by forest–pine (1981 to 1990) and rangeland (1990 to 1999). The decline of cultivation was mainly due to its conversion to mixed grassland, particularly from 1981 to 1990.

Accuracy assessment

The 3 classified images achieved satisfactory overall accuracies of 78% for 1981, 82% for 1990, and 86% for 1999 (Table 2). In 1981 the shrubland class received the lowest accuracy score, with 60% of pixels being correctly classified. Similarly in 1990, mixed grassland and shrubland had the lowest accuracy scores of 66.6% and 71.4% respectively. For the 1999 classification, most classes had relatively high accuracy scores. Both forest classes had high accuracy scores in all image dates.

Discussion

Forest conversion

The most dramatic land use change in the Xiaozhongdian area since 1981 was the decline of both forest types, and their conversion into shrubland (and to a lesser extent rangeland and mixed grassland). The average aggregate loss of both forest classes was 23%. This loss is almost certainly due to commercial logging activities up until the ban in 1998. The conversion of 23% of forest–fir to shrubland and rangeland, and 24% of forest–pine to shrubland from 1981 to 1990 probably reflects a combination of post-logging structural changes of the vegetation and dieback caused by insect infestation. The mid-1980s represent the peak period of timber extraction from the prefecture (Xu and Wilkes 2004). From 1990 to 1999 the area of forest continued to decline, albeit at a much slower rate, converting to shrubland or rangeland.

The forest–fir dominated northern plateau area was logged relatively late; but when logging started it was evidently extensive. This logging commenced after

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TABLE 2 Summary of classification accuracy assessment.

Class	1981		1990		1999	
	User	Kappa	User	Kappa	User	Kappa
Cultivation	81.2%	.801	91.6%	.911	91.3%	.894
Mixed grassland	68.7%	.663	66.6%	.645	84.6%	.806
Shrubland	60.0%	.550	71.4%	.648	85.1%	.793
Rangeland	77.7%	.743	87.8%	.860	71.4%	.703
Forest–fir	82.6%	.757	90.4%	.854	100%	1.00
Forest–pine	82.7%	.736	79.6%	.736	84.1%	.785
Overall	**78%**	**.716**	**82%**	**.765**	**86%**	**.817**

severe insect attacks had caused large areas of dieback. The logging of this area in 1992–1993 was followed by revegetation programs. The insect attack (*Cosmotriche saxosimilis* larvae) began in the autumn of 1984 and mainly affected high elevation *Abies georgei* forest (Lu Nan 1990). The 1990 image appears to show large areas of affected forest, though it is difficult to discern whether these areas had been logged or had just suffered dieback, thereby exposing the shrubby understorey. Since 1986 more than 20,000 ha of *Abies* forest have been pest-affected in Shangri-la County (Xu and Wilkes 2004).

The conversion of the forest classes to either shrubland or rangeland also reflects different post-logging forestry management activities, ranging from replanting selectively logged forests to plantation-style revegetation after clear-felling operations (particularly pine plantations in the southwest of the township). Reforestation activities have had varying degrees of success. In the southern plateau area (forest–fir and rangeland dominated) of Xiaozhongdian Township, for example, government companies logged (often clear-felling) and replanted every year from the early to the mid-1970s. Unsuccessful replanting was common, often due to the selection of inappropriate species; for example in some high elevation areas a non-local species of *Abies* was planted with little success. Many of these logged areas are now dominated by patches of deciduous species, such as bamboo, birch, maple, and willow. Similarly, for the northwestern plateau area revegetated in 1993–1994, the survival rate of trees was only about 40%—a rate considered unsuccessful by local forestry officials. On many hillslopes near villages, pine forests have been logged and replaced by deciduous species such as birch, and it is evident such areas are subject to livestock grazing, preventing forest regeneration and causing soil degradation. Cutting for firewood and fencing also appear to be having substantial impacts in regenerating forests adjacent to villages. Firewood collection has been noted as an important driver of biodiversity loss in northwest Yunnan (Xu and Wilkes 2004).

LULC conversion has also occurred from shrubland to other classes, including to both forest classes. This probably reflects where post-logging regeneration and/or replanting have been more successful or where deciduous species have been replaced by evergreen species, particularly further away from villages where utilization impacts are reduced.

The anecdotal and observational information described above helps to explain the significant two-way forest–shrubland conversions occurring during the study period, representing transitions between logging, variable regeneration, dieback, and other human-induced impacts. Significantly, these conversions suggest considerable structural changes occurring even during the 1990s when the reduction in overall forest cover slowed significantly. Thus, it is evident that forest cover statistics alone only give a partial picture of forest status.

Forest conversion and the 'big picture'

The overall decline of forest in Xiaozhongdian is at variance with the numerous reports of increasing forest cover in China, including Yunnan Province. However, it is difficult to reach conclusions about forest status from the 'big picture' figures. The published statistics are tabular representations of LULC cover over time, but without change analysis representation (eg Figures 5 and 6, or a matrix), one can only guess at what is being exchanged, leading to loss or gain. Even when the data are presented as more specific categories, the situation remains the same. For example, NFRI data show that since 1986 "natural forests," "plantation," and "shrubland" have been steadily increasing (FAO 2005). Howev-

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er, without knowing what actual conversions between categories have taken place, it is possible that natural forest is actually decreasing but being replaced with each assessment at a faster rate by areas of regenerating forest which were formerly included in other categories, such as open forest or shrubland (which in turn are being supplemented by other categories over time). With such a scenario, there may be forest quality—and thus biodiversity—implications if, for example, the figures are masking a replacement of mature or unique eco-regional forests with various forms of structurally and possibly floristically different regenerating forests.

Related issues concerning forest cover reporting have been raised by several researchers. Rozelle et al (2003) contend that because the FAO figures are based upon a transformed version of China's NFRI data due to the numerous changes in the definitions and criteria used between assessments, the figures may actually mask a net loss in natural forest cover and hide the fact that the gain is mostly composed of other forest categories such as plantations, 'engineered' forests, shelterbelts, and economic tree crops. Similarly, the World Research Institute (WRI) reports that in China (as in the rest of temperate Asia) plantation establishment has exceeded natural forest loss; this loss is hidden in the positive net change in total forest cover from 1990 to 2000. The WRI also sees an urgent need to establish standardized baseline information on forest cover and change, including the application of high-resolution satellite imagery (WRI 2001). Sayer and Sun (2003) state that "more rigorous indicator sets are needed to evaluate forest quality." In this regard, understanding the forest status in China could be improved by correlating the field-based NFRI data with finer-scale spatial datasets to enable quantitative change analyses in representative ecological regions.

The forest conversion trends in Xiaozhongdian are similar to those found in comparable local and regional LULC studies using similar data and mapping methodologies. In Yunnan's Mekong watershed, forest cover declined by 17% from 1990 to 1998, accompanied by a large increase in shrubland and sparse forest; the main causes of LULC change included logging, infrastructure development and cash crop plantations (Xu et al 2003). In the Indian central Himalayas between 1986 and 1996, Rao and Pant (2001) reported a small reduction in natural forest area but noted extensive structural changes (thinning and increasing patchiness) despite active government reforestation programs. The forest structural changes were mainly due to increased local community utilization.

Decline in cultivated land

The period from 1981 to 1999 saw a 37% aggregate decline in cultivated lands in Xiaozhongdian Township. Most of this converted to mixed grassland, particularly in the first half of the study period. This increase in pasture can be linked to an important period of agricultural transformation occurring across China. From 1978 to 1983, the Household Responsibility System granted farmers greater control and ownership over their cultivation and livestock management (Banks 2001; Xu and Ribot 2004). Between 1979–1981 and 1989–1991, approximately 4% of total cropland in China was converted to other uses (WRI 1994, in Seto et al 2002). In Yunnan many old cultivated areas were turned into pasture as the government promoted more intensive animal husbandry; northwest Yunnan in particular has seen a steady increase in livestock numbers from this period (Xu and Wilkes 2004).

Decline in rangelands

The aggregated decline in rangelands from 1981 to 1999 was 12%. The conversion of rangeland to shrubland, particularly in the latter half of the study period, probably relates to decreasing use by the local community. These alpine rangelands have traditionally been used for summer grazing, predominantly of yaks, yak-cattle hybrids, and pigs. However, due to changing livelihood strategies, there is diminishing interest and less family labor available for farmers to utilize the summer rangelands; therefore, rangelands are undergoing a succession to shrubland in some areas. Local government is also controlling the use of the rangelands. In 2004 summer grazing in the northern Xiaozhongdian rangelands was banned by the Shangri-la government. Also, since 1998 the government has been enforcing strict controlled burning regulations. Farmers used to burn *Rhododendron* and other woody species to promote rangeland pastures. It is likely these issues have bolstered the conversion of rangeland to shrubland, particularly from 1990 to 1999.

Limitations and accuracy assessment

The limitations of utilizing remote sensing data in mountainous areas are well documented: cloud and snow cover, topographic shadow, steep slopes, and access difficulties for fieldwork are common (Shrestha and Zinck 2001). Some of the above problems were overcome by masking shading and other probable unclassifiable areas. The transparent rules-based hierarchal approach to classification used a combination of data sources to improve the results.

The 1981 Landsat MSS image was more difficult to classify than the other Landsat satellite images, as evidenced by the lower accuracy assessment scores. This is mainly due to the comparative lower spectral resolution of the sensor. In terms of comparing the 3 classified images, it was not desired nor was it considered necessary to degrade the 1990 and 1999 Landsat images to

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match the coarser spatial resolution of the 1981 image, due to the broadly defined LULC classes and because forest fragmentation was not being investigated. However, it is probable that a small proportion of the LULC change observed from 1981 to 1990 is an artifact of this resolution difference and the limitations of classifying the older Landsat data.

In terms of ecological interpretation, it is also important to consider whether the conversion exchanges between LULC classes are an indication of seral stages or artifacts of methodological limitations. This is particularly pertinent when trying to classify the diverse shrubland community using the general FAO definition. For example, many degraded hill slopes logged prior to 1981 are dominated by deciduous tree species; since most of these trees would have shed their leaves by the time of image acquisition (late autumn to early winter), exposing the often shrubby understorey, the delineation of shrubland from some other classes may be blurred. The classification confusion matrices (data not presented) reveal that shrubland was most often confused with the forest classes and, to a lesser extent, rangeland.

This study was restricted by the lack of independent reference data for accuracy assessment of the 1981 and 1990 classified images, and the assessment therefore had to be a compromise. Similarly, finding training areas was challenging. However, during interviews with local people, we were able to confirm areas where LULC had remained unchanged throughout the study period.

Conclusions

Clearly there has been a decrease in forest cover over the last few decades in Xiaozhongdian Township, resulting from a combination of past logging activities and dieback due to insect attack. This decrease can also be interpreted as degradation in forest quality with significant conversions between mixes of non-forest cover classes. There has also been a conversion of cultivated lands to mixed grassland for grazing; though this trend is declining and some grasslands and rangelands now appear to be converting to shrubland. The decline in the rangelands is a concern for those who still depend on the high elevation grazing pastures during summer months, a practice unique to the northwest in Yunnan Province.

It is particularly pertinent to note the broad diversity of forest and shrubland states that are evident when adopting the general categories used in regional analyses. The diversity of structural and floristic states within the general forest category reflect differing forestry management activities and subsequent vegetation dynamics, together with the limitations of using remote sensing imagery in this mountainous area. The effects of forest dieback and utilization by local communities also contribute to the diversity of states within the forest category.

This study has relevance to the broader debate about the definition of 'forest' and its 'quality.' Although the study area is relatively small, this site typifies the topography, land uses, and vegetation of the montane headwater regions of southwest China. The results suggest that, when using accepted LULC definitions, there has been a decline in forest cover in Xiaozhongdian Township, despite active reforestation and afforestation programs. Further, the change analysis has highlighted that cover statistics alone that are used to describe increasing forest cover in China and Yunnan may not give an accurate representation of forest status, as they do not account for conversions and exchanges that occur between categories that can signify forest quality issues. This research in northwest Yunnan implies that these issues could be significant.

Our understanding of the status of China's forests could be improved by correlating the NFRI with finer-scale spatial datasets in representative ecological regions. Such local differences give a better understanding of regional changes and of the impacts on local rural communities that rely on forest resources. This study strongly supports the view that assessments of land use and forest cover need to place clear emphasis on the ecological and transitional status of vegetation communities.

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